Dreissenid Mussels:
Quagga Mussel *Dreissena bugensis*
Zebra Mussel *Dreissena. Polymorpha*
False Darkmussel *Mytilopsis leucophaeata*

Ecology: Quagga (*D. bugensis),* zebra (*D. polymorpha*) and the dark falsemussel (*M. leucophaeata*) are all invasive mussels that threaten Utah's waters. Closely related cousins, these species have similar characteristics that will collectively be referred to as *Dreissenid* mussels. *Dreissenid* mussels are small, freshwater, bivalve mollusks with elongated shells, typically marked by alternating light and dark bands (zebra stripes). Shell patterns in zebra mussels, however, can vary to the point of having only light or dark colored shells and no stripes. Color patterns in quagga mussels vary more, with black, cream, or white bands. They usually have dark concentric rings on the shell on their ventral side and are paler in color near the hinge. In general, *M. leucophaeata* resembles *D. polymorpha*, with young individuals being especially difficult to distinguish. Adult individuals are usually brownish in color without the stripe patterns that are typical to young individuals (Marelli and Gray 1983).

Zebra mussels range in size from 1-5 mm in their juvenile form to greater than 15 mm in the adult form. The quagga can grow slightly larger than the zebra mussel; up to 20-22 mm in size. *M. leucophaeata* is the largest of the three *Dreissenid* mussels and may reach a maximum size of 22 to 25 mm in length (Siddall 1980, Pathy and Mackie 1993). Another distinguishing characteristic that can aid in species identification is shell shape. The quagga has a convex ventral side and when placed on its side the quagga mussel will topple over, whereas the zebra mussel will not (Claudi and Mackie 1994). The shell shape of *M. leucophaeata* is less angular than in *D. polymorpha* and does not have the longitudinal ridge typical to *D. polymorpha*. The exact species identification of *M. leucophaeata*, however, is based on an internal shell structure, requiring microscopic examination of the structure for species identification (Marelli and Gray 1983).

Dreissenids have considerable genetic and morphological plasticity as well as broad environmental tolerances that enable them to live in a wide variety of habitats. *Dreissenid* mussels also have byssal threads that allow easy attachment to most surfaces including other living organisms (e.g. other mussels, crayfish and turtles). *Dreissenid* mussels even attach to each other, forming dense layered colonies up to one foot thick. Mussel densities of over 1 million individuals per square meter have been recorded in parts of Lake Erie. Though *Dreissenid* mussels can attach to living organisms, they typically adhere to hard surfaces such as: rocks, concrete, steel, pilings, metal grates, boat motors, boat hulls, docks, anchor lines, buoy lines etc. Extensive siltation, microalgae, fluctuating water levels, and antifouling coated surfaces limit colonization.

Dreissenid mussels are diverse, but also have some defined environmental limitations. Zebra mussels can live at water temperatures approaching freezing, but spawning stops below 10ºC, and growth slows as temperatures decline. Cold temperatures can also reduce density. Zebra mussels die when the water temperature falls to levels that would cause ice to form within their bodies. On the opposite end of the temperature spectrum, lethal high temperatures are reached at between 31ºC and 35ºC. Quagga mussels have a greater tolerance for cooler water temperatures than zebra mussels; thus, they have been found to colonize substrates at greater water depths. Observations and research suggest that the North American quagga mussel is a cold, deep-water form, contrasting with Ukraine populations where the quagga mussel thrives at higher temperatures. In North America, zebra mussels survive indefinitely at 30°C, but the quagga mussel exhibits high mortality at this same temperature (Mills et al. 1996). Although there are indications that quagga die at lower temperatures than zebra mussels, there are a few exceptional quagga populations that are as tolerant of elevated temperatures as zebra mussels, so the potential thermal range of this species may be higher than recent experiments indicate (Mills et al. 1996).

Temperature is also a key factor in spawning and fertilization of *Dreissenid* mussels. A minimum spawning temperature of 12°C has been reported for zebra mussels compared to a 9°C spawning temperature for quagga mussels, which suggests the zebra mussel cannot successfully colonize hypolimnial waters. Although, zebra mussels have been reported to survive in the hypolimnion, they cannot reproduce there (Claxton and Mackie 1998). In contrast, a female quagga mussel with mature gonads was found in Lake Erie at a temperature of 4.8°C, so areas that were thought to be immune to quagga mussel colonization may be at risk (Claxton and Mackie 1998).

M. leucophaeata is considered a warm water species that is able to live in temperate areas also. The majority of individuals, however, do not survive harsh winter conditions (Marelli and Gray 1983). Temperature also affects reproduction. According to Verween et al. (2005) the gamete maturation starts at about 13°C, which is slightly higher than that for *D. polymorpha*. The lower temperature limit for the survival of juvenile and adult *M. leucophaeata* is not known. This factor might limit the establishment of permanent populations in a highly seasonal environment where winter temperatures fall close to 0°C, as in the northern Baltic Sea.

Because zebra mussels need a good deal of calcium to form their shells, they need water containing calcium levels of 25 parts per million or greater. Potential for spawning is very low below 9 parts per million of calcium. Zebra mussels thrive in waters with pH levels between 7.5 and 8.7. The threshold for survival of adults is 6.5 (McCauley and Kott 1993) and for larvae, 6.9 (Mackie and Kilgour 1993). Zebra mussels also require relatively high oxygen concentrations. Little, if any, colonization will occur at dissolved oxygen concentrations less than 40 to 50 percent air saturation (McMahon and Ussery 1995). The optimal water velocity for colonization is between 0.09 to 1.0 meters per second. Colonization potential does not decrease until velocities either exceed 1.5 meters per second or drop below 0.075 meters per second (O'Neill 1996).

Salinity is also a limiting factor in the growth and survival of *Dreissenid* mussels. Zebra and quagga mussels, generally considered fresh water species (<0.5 parts per thousand or <0.05% total salinity), can inhabit brackish areas ranging from 0.2 parts per thousand (0.02%) to as high as 12.0 parts per thousand (1.2%) total salinity (MacNeill 1990). Where as the false darkmussel is a highly euryhaline species, occurring from fresh water to saline water exceeding 20 parts per thousand (2%) total salinity. According to Siddall (1980), *M. leucophaeata* is able to complete larval development in salinities up to 32 parts per thousand (3.2%) total salinity. The species occurrence in Europe is concentrated to estuarine areas with fluctuating salinity conditions. In Belgium, *M. leucophaeata* has established vigorous fouling communities in conditions where salinity varies from 0.8 parts per thousand (0.08%) to 10.3 parts per thousand (1.03%) total salinity during the reproductive period (Verween et al. 2005). Due to the wide salinity tolerance *M. leucophaeata* has been reported to coexist with *D. polymorpha* in Europe (Jenner and Janssen-Mommen 1993.) In North America the distribution of *M. leucophaeata* and *D. polymorpha* overlap especially when salinities are below 3.0 parts per thousand (0.3%) total salinity (Pathy and Mackie 1993).

In Utah, the brackish water areas associated with the major inlet bays and minor inlet drainages along the east and south sides of the Great Salt Lake support massive wetlands utilized by millions of waterfowl and other waterbirds. Salinity profiles are suggestive that *Dreissenid* mussels could inhabit those brackish wetland areas. For example, Farmington Bay evidences <0.5 parts per thousand (<0.05%) to 60 parts per thousand (6%) total salinity, while Bear River Bay evidences <0.5 parts per thousand (<0.05%) total salinity. And, typical salinity in the tributary flows through the brackish water wetlands prior to entering the Great Salt Lake average 13 parts per thousand (1.3%) to 30 parts per thousand (3%) total salinity depending on season of year. The main north and south arms of the lake would not be suitable habitat, since total salinity ranges from 260 parts per thousand (26%) to 280 parts per thousand (28%) in the North Arm and 70 parts per thousand (7%) to 150 parts per thousand (15%) in the South Arm (Pers. Comm. Clay Perschon. 2008. Aquatic Research Coordinator, Utah Division of Wildlife Resources). The potential invasion of *Dreissenid* mussels, including competition for plankton and algae resources, and the disposition for *Dreissenids* to stimulate botulism outbreaks could compromise the migratory waterbird populations associated with the Great Salt Lake ecosystem (Pers. Comm. 2008. Larry Dalton, Utah Division of Wildlife Resources, Aquatic Invasive Species Coordinator).

Dreissenid mussels produce microscopic larvae (veligers) that float freely in the water column at numerous depths. Females generally reproduce in their second year by expelling eggs in the spring and summer, which are fertilized outside of the body by males, depending on the water temperature. Spawning begins as ambient water temperatures reach approximately 12°C and peaks as temperatures reach the 15°C to 17°C range (Claudi and Mackie 1994). Spawning may be interrupted when temperatures exceed 28°C and will resume when temperatures cool below that threshold (Nichols and Black 1994). Spawning has occurred in the Great Lakes at temperatures as low as 10°C and larvae have been seen throughout the winter months. Yearlong spawning by quagga mussels seems to be evident in Lake Mead situated in the lower Colorado River drainage (Pers. Comm. 2008. Brian Moore, National Park Service, Lake Mead National Recreation Area, Aquatic Resource Coordinator). In contrast, *M. leucophaeata*, in Europe, typically have only one yearly spawning period of approximately four months (Verween et al. 2005). Dreissenid mussel spawning produces planktonic veligers approximately 40 microns in length that are capable of active swimming for one to two weeks. Within two to five weeks of hatching, the larval mussels become too large (200+ microns) and heavy to remain planktonic, and they begin to settle out of the water column (Nichols and Black 1994). At this point, the veligers must find a hard substrate upon which to attach themselves. Once attached, the lifespan of a *Dreissenid* mussel ranges from 3 to 9 years.

Dreissenid mussels have severe negative impacts on aquatic ecosystems, wreaking havoc on native organisms and native fish populations. *Dreissenid* mussels are filter feeders consuming phytoplankton and zooplankton from the water column. *Dreissenid* mussels are efficient and can filter up to 1 liter of water per day per individual. They have the capability of filtering an entire lake's volume in a matter of days. This leads to an increase in water clarity and greater penetration of sunlight, allowing development of unwanted macrophytes. Plankton is microscopic, and if substantially removed by *Dreissenid* mussels, allows the smallest and most basic part of the food chain to be broken, which can have devastating effects on life cycles of plants, animals, and fish. *Dreissenid* mussels can also pollute the water by encapsulating undesirable plankton, releasing a resultant pseudofeces back into the water to rot. Impacts associated with the filtration of water include increases in water transparency, decreases in mean chlorophyll, and concentration and accumulation of pseudofeces (Claxton et al. 1998). Increased amounts of pseudofeces in the water have been associated with poor water quality, foul odor and taste. As the waste particles decompose, oxygen is used up, the pH becomes very acidic, and toxic byproducts are produced. In addition, *Dreissenid* mussels accumulate organic pollutants within their tissues to levels more than 300,000 times greater than concentrations in the environment, impacting predators who consume the mussel. Also, the pollutants are bound in the pseudofeces, which can be passed up the food chain; therefore, increasing wildlife exposure to organic pollutants (Snyder et al. 1997).

Distribution:

Zebra mussels

Zebra mussels are native to the Black, Caspian and Azov seas. They were first introduced into North America by transoceanic ships, entering the Great Lakes system around the mid 1980's, ultimately being discovered in the United Stated during 1988 in Lake St. Clair. Since introduction they have spread throughout the Great Lakes region, along its major tributary and effluent rivers (O'Neill 1996). In 2007 it was evident that they had crossed the 100th meridian, invading Pueblo Reservoir in south-central Colorado (Pers. Comm. 2008. Elizabeth Brown, Aquatic Invasive Species Coordinator, Colorado Division of Wildlife) and San Justo Reservoir in west-central California (Pers. Comm. 2008. Susan Ellis, Aquatic Invasive Species Coordinator, California Fish and Game). *Dreissenid* mussels have been interdicted alive on trailered boats in California, Washington, and British Columbia (Pers. Comm. 2008. Susan Ellis, Aquatic Invasive Species Coordinator, California Department of Fish and Game; Pers. Comm. 2008. Allen Pleus, Aquatic Invasive Species Coordinator, Washington Department of Fish and Wildlife; Pers. Comm. 2008. Leif-Matthias Herborg, Provincial Aquatic Invasive Species Coordinator, British Columbia) as well as at many other areas of the nation. Those apprehensions resulted in decontaminations to kill the mussels.

Quagga mussels
Quagga mussels are indigenous to the Dneiper River drainage of Ukraine and are now abundant in the Great Lakes region. This species was first documented in the Great Lakes in September 1989, and after confirmation that the mussel was not a variety of zebra mussel, the new species was named "quagga mussel" after the quagga, an extinct African relative of the zebra (O'Neill 1996). More recently quagga mussels have established themselves west of the 100th meridian, probably being transported on a trailered, recreational boat. In 2007, quagga mussels were confirmed in Lake Mead, Lake Mojave and Lake Havasu along the lower Colorado River (Pers. Comm. 2008. Brian Moore, National Park Service, Lake Mead National Recreation Area, Aquatic Resource Coordinator). Downward drift of planktonic veligers in the Colorado River and via its diversions has resulted in widespread contamination of the entire lower Colorado River Basin. These contaminations include waters served by the Southern California Aqueduct in California (Pers. Comm. 2008. Susan Ellis, Aquatic Invasive Species Coordinator, California Department of Fish and Game) and the Central Arizona Project, including the Salt River Project in Arizona (Pers. Comm. 2008. Tom McMahon, Aquatic Invasive Species Coordinator, Arizona Game and Fish Department).

Dark falsemussels
The dark falsemussel is a brackish water species with an original distribution in the subtropical and temperate Gulf of Mexico area (Marelli and Gray 1983). The current distribution along the North Atlantic west coast extends north to Massachusetts in the United States (Smith and Boss 1996). The first record of this species in Europe was made in Belgium during 1835 (Verween et al. 2005), where it was probably transported by the shipping industry. In northwestern Europe, *M. leucophaeta* currently occurs in estuaries along the North Sea coast from Germany to France and into Great Britain (Oliver et al. 1998 and Verween et al. 2005).

<u>Pathways of Introduction</u>: The rapid invasion of North America and recent expansion of *Dreissenids* into the west has been exponential due to their ability to disperse at all different stages of life. *Dreissenid* mussels disperse in many different ways. The first way they move is naturally, being carried passively as planktonic larvae (veligers) in flowing or wind-driven (wave) water currents and by attaching themselves to other organisms such as crayfish or turtles. They may also attach to legs, feet, and feathers of waterfowl and shore birds, but transport on animals is only a low-level vector (Carlton and Johnson 1993). *Dreissenid* mussels are most typically transported by humans within vehicles or vessels capable of storing and moving water. Recreational boating and the ability to move boats and other equipment long distances in short periods of time is the primary vector and has increased the potential spread of these mussels. All life forms of *Dreissenid* mussels can be transported in many ways including the following: ballast systems, live wells, bait wells, bilge tanks, ski storage areas, cooling systems, and basically anywhere water can be stored on a boat. Adult *Dreissenid* mussels are more likely to attach themselves to boats and equipment and can survive several days out of the water. Some adults have been known to survive up to 27 days in the right conditions of cool temperatures and high humidity. Their veligers are more susceptible to dying in hot, dry

conditions (McMahon and Ussery 1995). All human forms of introduction can be prevented if the proper precautions and decontamination procedures are followed.

Management consideration: Monitoring and control of *Dreissenid* mussels costs millions of dollars annually, and could cost water users in Utah upwards of 15 million dollars a year in additional maintenance costs for water delivery and use systems (Pers. Comm. 2008. Mike Suflita, Senior Engineer, Utah Division of Water Resources). *Dreissenid* mussels have the biofouling capabilities of colonizing water supply pipes, inhabiting hydroelectric power plants, disrupting public water supply plants, and in all cases reducing water flow drastically, which increases the maintenance costs at industrial facilities (O'Neill 1996). *Dreissenid* mussels are a threat to more than just the world of recreational water use of boating and fishing. They are a threat to (1) every person who turns on the tap to get a glass of water; (2) every person or industry that utilizes water; and (3) every farmer who uses irrigation pipes or canals to move water to their crops (Pers. Comm. Larry Dalton. 2008. Aquatic Invasive Species Coordinator, Utah Division of Wildlife Resources).

Many different approaches to management of *Dreissenid* mussels have been considered and executed, most resulting in only limited success. To date, no single "silver bullet" *Dreissinid* mussel control technology has been identified. None will work in all water settings, and many control measures pose significant risks to the environment. However, a wide variety of control methods do exist for *Dreissenid* mussels, and many are suitable or practical for some situations. The following information, gleaned from the U.S. Bureau of Reclamation's draft (2008) "Upper Colorado Region Prevention and Rapid Response Plan for *Dreissenid* Mussels," utilized the database on the U.S. Army Corps of Engineers' website www.el.erdc.usace.army.mil/zebra/zmis/idxlist.htm.

Non-chemical Control (U.S. Bureau of Reclamation 2008)
Table 2 (Author's Note: No Table 1 is presented) presents information on an array of non-chemical methods for controlling *Dreissenid* mussels. Also, if equipment or components at facilities or structures infested with *Dreissenid* mussels can be removed and replaced or if backup systems can be used, a response for control or maintenance can be rapid and effective. In accessible areas, mussels can be physically removed by a variety of means, including scraping, suction, pressure washing or pigging. Pigging would not be practical in pipes and conduits with lots of bends or size changes. Suction dredges might be used to remove mussels from bottom sediments. Also, pressures washing with 2,000 to 3,000 psi should remove mussels, but it may take 4,000 to 10,000 psi to remove their byssal fibers (the fibers that they use to attach to hard surfaces). While the byssal fibers may not have to be removed to substantially improve water flow, their presence could allow increased corrosion of metal surfaces by anaerobic bacteria. Physical removal of *Dreissenid* mussels can be labor intensive and time consuming, which may pose problems for completing their removal within necessary facility operational time frames. Once the mussels are removed, they will have to be disposed at a local land fill. The potentially large volume of dead and putrefying mussels must be considered when choosing physical removal.

Dreissenid mussels are susceptible to exposure and desiccation. They are more sensitive to longer exposure times than either higher temperatures or freezing. Dewatering as a control measure may be particularly appropriate for canals. If dewatering is an option, operations should plan on dewatering a facility for a minimum of three weeks in non-freezing temperatures. This can be reduced to about a week if air temperatures can be raised to > 25°C. Freezing will kill mussels within a day although exposure time will need to be increased to a few days if there are clumps of mussels to assure thorough freezing. After a facility is re-inundated, there will still be dead mussel bodies and shells to collect and transport to appropriate land disposal locations.

In projects or systems that cannot be dewatered, consider isolating limited areas for either treatment with hot water or other methods to achieve oxygen deprivation (anoxia). The water temperature needs to reach 33-35 °C to assure a kill and this should be repeated once or twice a year for longer-term applications. For oxygen deprivation to work, the system must be well sealed as the mussels will survive for long periods in low-oxygen environments. Depending on water volume and mussel density, it could take several weeks for a system to go sufficiently anoxic to assure a kill. This can be accelerated if the water is warmer (25 °C) or if certain chemicals, such as hydrogen sulfide gas or sodium metasulfite, are added to eliminate oxygen. Additives should not be used without consideration of their potential impacts in discharge water. As with desiccation, there will be mussel disposal requirements post-treatment.

Table 2. Non-chemical treatments methods for controlling *Dreissenid* mussels (U.S. Bureau of Reclamation 2008).

Method	Life Stage	Effectiveness	Duration of Treatment	Notes
Oxygen starvation	All		2 weeks + @ 0 mg/l	Must isolate population; Useful reservoir management scheme if hypolimnion can be increased
Freezing	Juveniles	100%	2 days @ 0°C	Must dewater system
	Adults		5-7 hours @ -1.5°C	
			under 2 hours @ -10°C	
Desiccation	Juveniles	100%	Immediate @ 36°C	Must dewater system for several days
	Adults		5 hours @ 32°C	
			2.1 days @ 25°C	
Cavitation	All	100%	veligers in seconds @ 10-380 kHz	May affect other species, reduced success in high flows, needs power source
			juveniles in minutes	
			adults in a few hours	
Ultrasound	All	100%	veligers in seconds @ 39-41 kHz	May impact other species, needs power source
			adults in 19-24 hrs	
Vibration	Veligers, juveniles	100%	intermittent @ 200 Hz & 10-100 kHz	Structural integrity may be threatened
UV radiation	All	100%	juveniles -4 hrs	Lethal to many species, effectiveness limited by turbidity and suspended solids
			adults – continuous	
Benthic mats (disposable subsrates)	Juveniles, adults	Up to 99%	9 weeks	Initial tests promising for limited infestations

Bacterial toxin, *Pseudomonas fluorescens* (experimental)	All	95%	6 hours	Low toxicity to other organisms, few treatments needed, not yet available in commercial quantities.
Low frequency sound	Juveniles	Inhibits settling	4 to 12 min @ 20 Hz – 20 kHz	Not lethal, needs power source
Low voltage electricity	Adults	Prevents settling	immediate results @ 8 volt AC	Not lethal, needs power source
Plasma pulse technology	Juveniles, adults	Prevents settling	intermittent high energy pulses	Not lethal, private technology
Manual removal (scraping, mechanical filtration)	Juveniles	Variable	N/A	
	Adults			
Electric field pulse	Juveniles, adults	Lethal to juveniles	seconds	May affect other species, needs power source
		Inhibits adult settling		
Predation	All	Low	Continuous	Harvest of potential predatory species must be limited

Biological Control (U.S. Bureau of Reclamation 2008)
Biological control options are extremely limited at this time. Some diving-ducks (e.g., lesser scaup), crayfish, raccoons, and some fish (e.g., freshwater drum, carp, and some sunfish) will feed on *Dreissenid* mussels. Unfortunately, none of these predators are known to prey on the mussels to the point of controlling populations. Generally, predator animals are not feasible inhabitants within the inner workings of project facilities.

Research is ongoing to determine if any known mussel parasites (e.g., trematodes and annelids) or microbes could be used to control zebra mussels. Research involving a bacterial toxin, *Pseudomonas fluorescens*, is being conducted. Laboratory results at the New York Museum show a potential to kill 100% of zebra mussels and 85% of quagga mussels fed the cultured, dead *Pseudomonas fluorescens*. Progress continues toward commercialization of this bacterial toxin, with an expectation of it being available as early as 2010 (Pers. Comm. Dan Malloy. 2008. Research Coordinator, New York Museum). More information is available on the National Energy Technology Laboratory website:
http://www.netl.doe.gov/technologies/publications/factsheets/project/Proj291.pdf.

Unfortunately, at this time bio-control seems unlikely to provide near term benefits for infested project facilities or open water situations. However, this plan will be updated if organisms are identified that may be useful.

Chemical Control (U.S. Bureau of Reclamation 2008)
Tables 3 and 4 present information on an array of both non-oxidizing and oxidizing chemicals for controlling *Dreissenid* mussels. Chemical controls fall into two general categories, those that are lethal and those that are irritants (generally oxidizing chemicals) that discourage settlement or inhibit respiration, growth, or metabolic function of *Dreissenid* mussels. General information is provided to illustrate possible chemical control options. But, because of their potential impacts on non-target organisms, including species and critical habitats listed for protection by the Endangered Species

Act, prescriptive alternatives will be left for later development and coordination in a water specific rapid response plan. Information about chemical control methods will be periodically updated in this plan, particularly if new, effective chemical products become available.

Lethal chemicals include molluscicides, copper sulfate, and certain metal ions (e.g., potassium). These may be used with or without detoxification and some are proprietary (e.g., Clam-trol). Use of chemicals will also likely require an applicator permit and performance under the auspices of a National Pollutant Discharge Elimination System (NPDES) permit from the Environmental Protection Agency. Copper sulfate and most metal ions are also toxic to other organisms in local water bodies and would have to be contained.

Oxidizing chemicals approved for use in drinking water, such as chlorine, potassium permanganate, ozone, and bromine, are effective in controlling mussels but they also impact non-target organisms and may result in adverse environmental impacts. Sodium hypochlorite (NaOCl) injection systems have been used by the Ontario Power Generation in Canada. Another product, BioBullets, has been developed that uses the encapsulation of an active ingredient (KCl) in microscopic particles of edible material designed for ingestion by mussels. It is also supposed to negatively affect the Asian clam *Corbicula fluminea*.

Table 3. Chemical treatment methods for controlling *Dreissenid* mussels (U.S. Bureau of Reclamation 2008).

Treatment	Target Age	Efficiency	Contact Time, Concentration	Comments
NON-OXIDIZING CHEMICALS				
Copper ions	Veligers	100%	24 hours @ 5 mg/l	Lethal to other aquatic species
Potassium ion (KOH)	All	100%	Less than 10 mg/l	As above
Potassium ion (KH2PO4)	All	100%	continuous @ 160-640 mg/l	As above
Potassium salts (KCL)	Juveniles, adults	Prevent settlement	50 mg/l	Lethal to other mussel species, non-toxic to fish at required dose rate
	All	50%	48 hrs @ 150 mg/l	
		95-100%	3 weeks @ 95 – 115 mg/l	
Chloride salts (Nail,)	Veligers/ juveniles	95-100%	6 hours @ 10,000-20,000 mg/	Low cost, low environmental Impacts, very high dosage rates
Copper sulfate	All	55%	5 hrs 300 mg/l @ 22.5 °C	Lethal to other aquatic species
		40%	5 hrs 100 mg/l @ 22.5° C	
		50%	48 hrs 2 – 2.5 mg/l @ 17 C	
OXIDIZING CHEMICALS				
Chlorine	Veligers	100%	0.25-5mg/l in 1 to 9 days	Lethal to many aquatic species
	All	90%	2.0 mg/l continuous	
	Adults	95%	0.3 mg/l 14-21 days	
	Adults	75%	0.5 mg/l 7 days	
Chlorine dioxide ClO2	Veligers	100%	0.5 mg/l 24 hours	Most successful on veligers
Chloramine	Veligers	100%	1.2 mg/l 24 hours	Less toxic to other aquatic life than chlorine
		95%	1.5 mg/l continuous	
Hydrogen peroxide	Veligers	100%	6 hours	High dosage rates required. Lethal to other

	Juveniles			aquatic species
Ozone	All	100%	Veligers in 5 hours @ .5 mg/l Adults in 7 days @ .5 mg/l	Lethal to other aquatic species
Potassium permanganate	All	90-100 %	2.0 mg/l for 48 hours	Must have high continuous dosage, lethal to other species

Table 4. Non-oxidizing commercial products available as chemical treatment methods for controlling *Dreissenid* mussels (U.S. Bureau of Reclamation 2008).

Treatment	Target Age	Efficiency	Contact Time, Concentration	Comments
QUATERNARY AMMONIUM COMPOUNDS				
Clam-Trol CT 1	All	100% 48 hours after exposure	1.95 mg/l @ 11 °C for 12 hours	More toxic to veligers than adults and more toxic to mussels than to trout
			1.95 mg/l @ 14 °C for 14 hours	
			1.95 mg/l @ 20 °C for 6-14 hours	
Calgon H-130	All	100% after 48 hours	0.85-1.12 mg/l	1.1 mg/l toxic to salmonids, must be deactivated, corrosive, flammable
Macro-Trol 9210	All	100%	5-50 mg/l continuous	Lethal to aquatic organisms, must be detoxified
Bulab 6002	All	100%	2 mg/l 7-10 days	Lethal to fish, especially salmonids
			4 mg/l 5-8 days	
AROMATIC HYDROCARBONS				
Mexel 432	Veliger	Deters veliger settlement	Dose at 1-4 mg/l once a day	96 hr LC 50 for rainbow trout 11mg/l, corrosive
EVAC – endothal formulation	All	100%	0.3-3 mg/l for 5 to 144 hours	Lethal to fish but rapidly degrades, does not bio-accumulate
Bulab 6009	All	100%	2 mg/l 4 to 10 days	96 hr LC 50 for rainbow trout 1,1 mg/l, corrosive
			4 mg/l 3 to 8 days	

Note: Products listed in Table 4 have been approved for aquatic use by EPA if applied according to label instructions by a licensed applicator. They may not be approved by the individual states and must have that approval before they can be applied. The molluscicides have been primarily developed for use at water impoundment and hydropower facilities, treatment facilities, water intake structures, etc. Their use in open water is not generally recommended, but might be possible under certain circumstances.

Other Control Methods

Settlement of *Dreissenid* mussels within water conveyance systems or water use facilities can generally be deterred by providing flows that exceed 1.5 meters per second. However, corners, short radius bends and pipe joints or other "edges," including roughened pipe walls from scaling can become inhabited by mussels (Jenner and Janssen-Mommen 1989 and O'Neill 1996). Similarly, the application of anti-fouling coats (e.g, copper-based paints and over-lays of copper on exterior metal surfaces) has shown some success at deterring settlement by all life stages of *Dreissenid* mussels. Generally these surfaces create an irritant to the fouling organism, so it is reluctant to attach, and in some cases the coatings can be toxic to the fouling organism (O'Neill 1996).

The application of extremely low frequency electromagnetic fields within industrial water transport systems may be an effective method for the control of a *Dreissenid* infestation, since zebra mussels showed mortality within 5 days using this procedure (Matthews 1998). Research is believed to be continuing on this methodology at Purdue University-Calumet.

Reservoir management schemes that draw water from the oxygenated epilimnion, increasing the anoxic zone of the hypolimnion, can be utilized to manage *Driessenid* populations. The mussels in the lower, anoxic zone die from oxygen deprivation. Winter draw-downs also provide opportunity to freeze exposed reservoir literal zones, killing huge population segments of *Dreissenid* mussels. This approach requires significant consideration for safeguarding a water body's fishery, and it does not cause a 100% kill of *Dreissenid* mussels, but it does provide some degree of population management.

Decontamination of Boats and Construction Equipment
Equipment (e.g., boats, recreational equipment and construction equipment) exposed to waters infested with *Dreissenid* mussels should be decontaminated before being moved from the infested water. The 2008 Utah Legislature passed the Aquatic Invasive Species Interdiction Act (Senate Bill 238) and subsequently the Utah Wildlife Board passed associated rule (R657-60, Aquatic Invasive Species Interdiction), both with a purpose to define procedures and regulations designed to prevent and control the spread of aquatic invasive species, particularly *Dreissenid* mussels, within the State of Utah. It is unlawful to possess or transport *Dreissenid* mussels within the State of Utah. Additionally, all boats having been used anywhere within the last 30 days on a *Dreissenid* mussel infested water, either marine or fresh, and subsequently launching on any waters in Utah must certify prior to launch that they have been properly decontaminated. Launch is denied until certification can be met. The only two accepted decontamination protocols in Utah as per Rule R657-60 are as follows:

<u>Do-it-yourself Decontamination</u>

- Clean all plants, fish, mussels and mud from boat or equipment before leaving water body area (discard unused bait in the trash where you fished);
- Drain all water from boat (equipment storage areas, ballast tanks, bilge, live wells and motor) before leaving water body area;
- Dry boat and equipment at home or at suitable storage area (7 days summer, 18 days spring and fall, and 30 days winter or expose boat and equipment to freezing conditions for a continuous 72 hour period) prior to another launch.

<u>Professional Decontamination</u>

- Use a professional to apply scalding water (140^0 Fahrenheit) to wash equipment, boat and trailer and to flush equipment storage areas, ballast tanks, bilge, live wells and motor or other raw water circulation systems.

Either of the aforementioned decontamination protocols for boats and equipment will kill the aquatic invasive species either already inhabiting Utah or threatening to arrive, including adult, juvenile and microscopic life forms (Pers. Comm. 2008. Larry Dalton, Aquatic Invasive Species Coordinator, Utah Division of Wildlife Resources).

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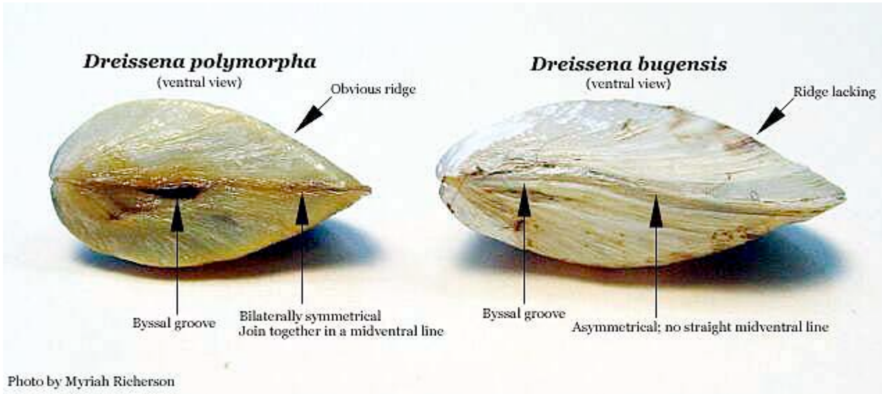
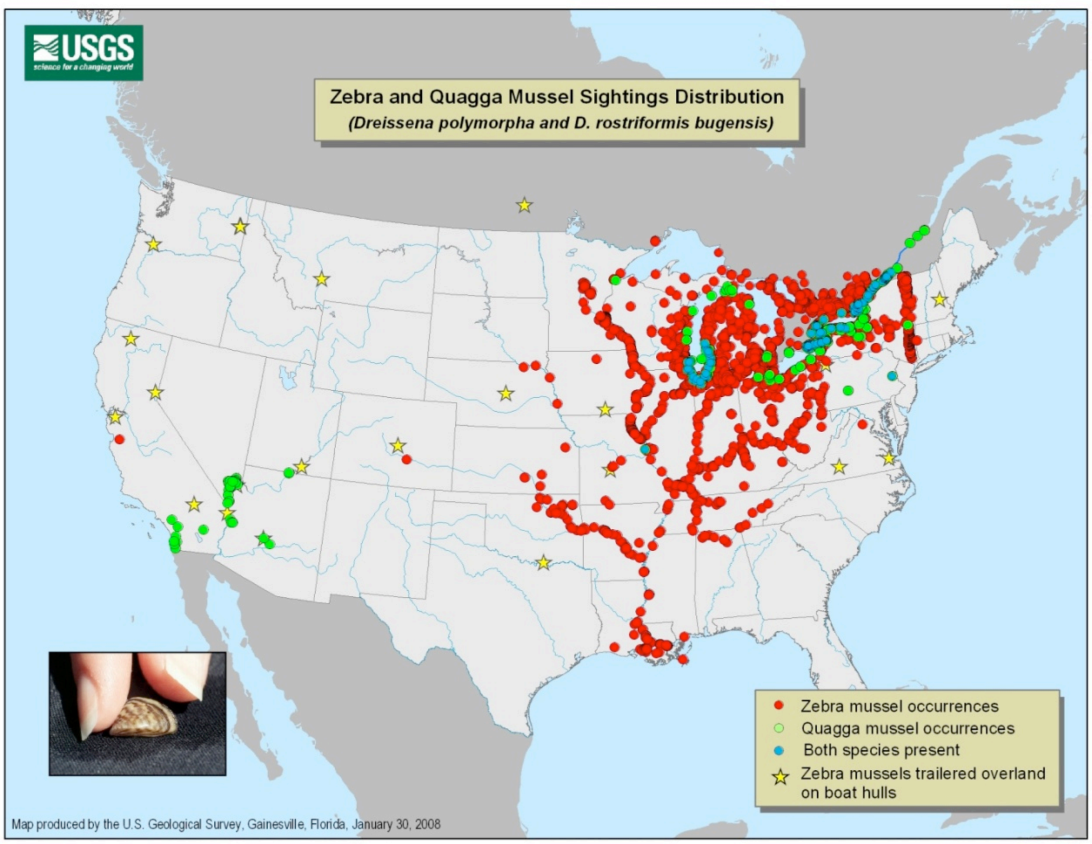

Dreissena polymorpha
(ventral view)
Obvious ridge
Byssal groove
Bilaterally symmetrical
Join together in a midventral line
Dreissena bugensis
(ventral view)
Ridge lacking
Byssal groove
Asymmetrical; no straight midventral line
Photo by Myriah Richerson


USGS
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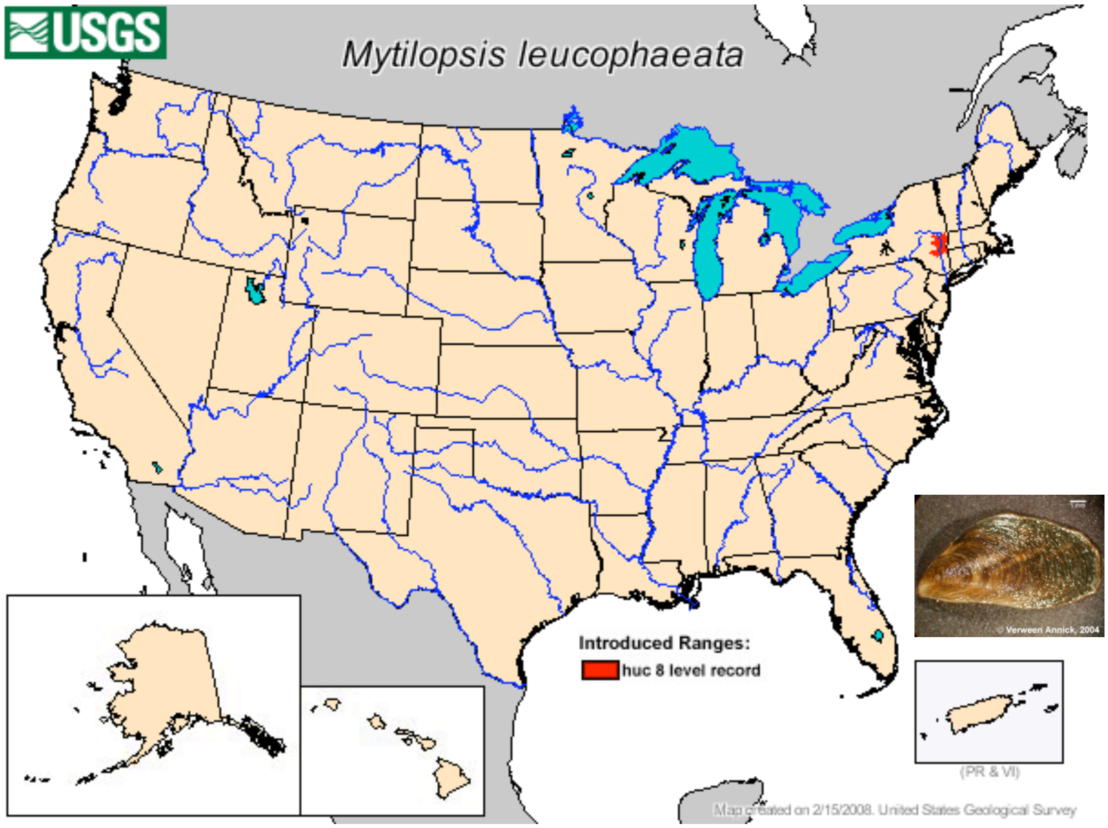
Zebra and Quagga Mussel Sightings Distribution
(Dreissena polymorpha and D. rostriformis bugensis)
Zebra mussel occurrences
Quagga mussel occurrences
Both species present
Zebra mussels trailered overland on boat hulls
Map produced by the U.S. Geological Survey, Gainesville, Florida, January 30, 2008


USGS
Mytilopsis leucophaeata
Introduced Ranges:
huc 8 level record
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(PR & VI)
Map created on 2/15/2008. United States Geological Survey